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The Measurement of Absorptive Capacity from an Economics Perspective: Definition, Measurement and Importance

By

Richard Harris* and Ji Yan**

Abstract

This paper starts by recognising that despite the importance of absorptive capacity, economists in particular have made only limited use of the concept. Most theoretical and empirical studies derive from other fields of research. Thus, the first task is to compare and contrast the different approaches taken in measuring absorptive capacity. The rest of the paper then sets out an example of how typically economists have proceeded, using nationally representative CIS data to measure absorptive capacity across a 10-year period and investigating if it remains stable in the long term. This is followed by considering how firms' characteristics vary across lower to higher levels of absorptive capacity and whether such capacity determines firms' productivity performance across both goods and service industries. Our results show that relative to other influences, absorptive capacity as measured here – net of the impact of foreign-ownership and human capital – has a substantial influence on exporting, innovation and undertaking R&D, and thus consequently firm-level productivity. Finally, there is a discussion of why governments should consider helping firms to boost their levels of absorptive capacity.

JEL codes: L25; O24; O32; R11

Keywords: exports; R&D; innovation; absorptive capacity

* Department of Economics & Finance, Durham University Business School, Mill Hill Lane, DH1 3LB, UK. Email: r.i.d.harris@durham.ac.uk

** Department of Management & Marketing, Durham University Business School, Mill Hill Lane, DH1 3LB, UK. Email: ji.yan@durham.ac.uk.

1. Introduction

Absorptive capacity, often defined as the ability of firms to internalise external knowledge, is a construct that has been widely used since its inception in the late 1980s/early 1990s (cf. Cohen and Levinthal, 1989, 1990). It extends to more than the ability of firms to benefit from spillovers which increase their chances of innovating; it is about the ability of firms to improve their productivity more generally as they assimilate knowledge from the external environment in which they operate. This has important consequences for policy initiatives like the new industrial strategies that are coming back into vogue in many economies. If firms are not able to learn, and hence gather and make effective use of information from outside the firm, then industrial strategies designed to help firms become more productive are likely to have only a limited impact. This paper aims to compare and contrast the different approaches taken in measuring absorptive capacity, with a particular emphasis on an economics perspective; to test whether firms remain the high (low) levels of absorptive capacity for long periods; to examine how the impact of firms' characteristics (e.g., firm size) varies across different levels of absorptive capacity; and to investigate the impact of absorptive capacity on the propensity of firms to innovate, undertake R&D and export.

The concept of absorptive capacity is related to the role and use of intangible assets (which can be defined as knowledge embodied in intellectual assets); the latter are recognized as a key driver of enterprise performance (e.g., Eustace, 2000; Corrado *et. al.*, 2011; Haskel, 2015) and thus ultimately aggregate productivity, and their role derives from the 'resource-based' theory of the firm (e.g., Penrose, 1959; Barney, 1991; Kogut and Zander, 1996; Teece *et. al.*, 1997). However, there are significant difficulties in measuring these assets (OECD, 2006), both from a theoretical and empirical standpoint. And in addition, building intangible assets requires that firms understand how to create new knowledge from the resources they possess (see Harris and Moffat, 2013, section 2 for a discussion). Through a combination of organisational routines and processes, firms must apprehend, acquire, share, assimilate, transform and exploit new knowledge in order to compete and grow in markets;[1] this ability to exploit internal and especially external knowledge is a critical component of a firm's capabilities and it constitutes the firm's "absorptive capacity" (Zahra and George, 2002). Absorptive capacity starts from

[1] Garcia-Morales et. al. (2007) set out in more detail what it means to acquire, assimilate, transform, and exploit (see especially p. 531). In particular, they note that "absorptive capacity is a dynamic capability that influences the firm's ability to create and deploy the knowledge necessary to build other organisational capabilities [i.e. other intangible assets]" (p. 528; note the text in parenthesis has been added to the original); in this sense absorptive capacity is itself an intangible asset.

firms wanting to absorb external knowledge but the ability of the firm to understand external knowledge, to assimilate it, to transform it, and to apply it, depends on the level of its prior (stock of) knowledge which presupposes the firm having invested in its own internal absorptive capacity, with the latter often associated with the firm's own internal R&D and/or human capital [2] (Cohen and Levinthal, 1989, 1990; Mowery et. al., 1996; Stock et. al., 2001; Carayannis and Alexander, 2002; Todorova and Durisin, 2007; Tsai, 2009). Thus, acquisition of internal and external knowledge is complementary (and indeed they are interrelated and both are necessary – Veugelers, 1997; Teece, 2000; Caloghirou et. al., 2004; Garcia-Morales et. al., 2007).

Despite the importance of the concept, this is an area that has only seen limited use in economics (notable examples are Keller, 1996; Griffith et. al. 2004; and Harris and Li, 2009), with most of the theoretical and empirical literature relating to absorptive capacity being published in business journals. For example, in an early review of the literature, van den Bosch et. al. (2003) cited only 6 out of 65 publications from established economics journals (with one of the latter being the seminal contribution by Cohen and Levinthal, 1989). Later reviews by Camisón and Forés (2010) cite 2 economics journals (from 64) while Hurtado-Ayala and Gonzalez-Campo (2015) refer to only 4 economics publications (from 89 cited).[3] Therefore section 1 provides a critical review of the (empirical) literature from more of an economics perspective (Camisón and Forés, op. cit., provide a thorough review based on the more prevalent business literature). The emphasis is on being able to measure absorptive capacity using larger (nationally representative) datasets, covering many countries and for significant time periods, where firms are asked to state if certain activities are taking place, rather than for example asking managers to complete (usually) small-scale cross-sectional surveys which rely on their self-assessed ability to search, obtain and use information and adapt existing technologies using such new information.

Economists are also generally more interested in using formal statistical modelling techniques that relate absorptive capacity to its impact on firm performance, such as productivity (and its underlying determinants, such as R&D, innovating and exporting). Thus section 2 of this paper

[2] Muscio (2007) stresses the importance of human capital over (formal) R&D in the case of SMEs.

[3] Figure S.1 in the unpublished appendix shows that for the period 1999-2018, only 18% of journal articles where 'absorptive capacity' appears as a keyword or in the abstract were published in economics journals (as defined by Scopus), with over 50% published in Business & Management, with the rest in Decision Sciences or more general Social Science journals. Table S.1 (unpublished appendix) also shows that in Economics journals, measuring the concept is largely confined to using R&D as a proxy – see discussion below.

provides an example (contrasted with the approach generally used in the business literature) based on our own preferred way to measure the concept, using factor analysis and structural equation modelling (SEM) and a nationally representative firm-level database (the UK Community Innovation Surveys, 2004-14). Before modelling the underlying determinants of productivity, section 3 provides more detailed analysis on which firms (in terms of their characteristics) are more likely to have higher levels of absorptive capacity, as well as information on whether its distribution is stable across time (i.e., do firms with high levels retain their position over time). This is an extension of previous work, and indicates that building absorptive capacity takes time and is persistent. We then use the SEM approach to measuring absorptive capacity (in Section 4) to consider its influence over 2004-14 in determining the propensity of firms to innovate, undertake R&D and export, after taking into account other factors that determine these productivity-enhancing activities. Lastly there is a brief discussion of how government policy can be used to build absorptive capacity, including the key issue of whether policy should help firms directly to increase their own absorptive capacity or should the emphasis be on supporting networks (the environment outside the firm), given that the latter may be a major source of knowledge spillovers? The paper ends with a summary and conclusions.

2. Defining and measuring absorptive capacity

There is no one, accepted definition of the latent variable absorptive capacity; it is often stated that "no single (definition) is superior to all others, under all circumstances" (Escribano et. al., 2009, p. 99). Nonetheless, Shenkar et al. (1995) state that the definition of a construct domain must fulfil two requirements: the construct must be testable and it must also be global, that is incorporate the dimensions that different classifications propose. The original definition by Cohen and Levinthal (1989) defines absorptive capacity as the ability of the firm to learn from external knowledge through the processes of knowledge identification, assimilation and exploitation. These authors argued that an organisation's R&D efforts was a sufficient proxy for absorptive capacity; however, in their 1990 paper, Cohen and Levinthal widen the definition to not only include R&D activities but also the wider knowledge base, prior learning experience and other factors associated with problem-solving in the organisation. Probably the most common proxies used for absorptive capacity since have been some measure of R&D and/or of human capital (e.g., Stock et. al., 2001; Romijin and Albaladejo, 2002; Leahy and Neary, 2007; Cassiman and Veugelers, 2002, 2006; Becker and Peters, 2000; Keller, 1996;

Vinding, 2006; Spanos and Voudouris, 2009; Escribano et. al., 2009; Moilanen et. al., 2014);[4] even though there is a general consensus that neither is sufficient to capture fully the construct being measured (cf. Flatten et al, 2011; Lane et al, 2006), especially if absorptive capacity is viewed as an antecedent that in part determines whether firms (continue to) invest in R&D and/or human capital. That is, a measure such as R&D does indeed provide direct information on whether internal absorptive capacity is present, especially when adopting Cohen and Levinthal's (1989) "two-faces" of R&D argument that, firstly undertaking R&D produces internal knowledge that in part leads directly to, say, innovation; and secondly, undertaking R&D also partly increases absorptive capacity itself,[5] which in turn can impact on innovation. Thus, using R&D (or human capital) as an indicator of (internal) absorptive capacity is not invalid, although (as stated above) it is unlikely to capture fully the construct. Using both R&D and some additional proxies of absorptive capacity (linked to external knowledge generation), possibly with these proxies having a moderating role as well as direct effects, is more likely to capture the underlying processes when modelling, for example, innovation outcomes. As will be seen in section 4 below, we take this type of approach, by including direct measures of (mostly external) absorptive capacity along with past (i.e., lagged) values of R&D (plus innovation and exporting) in determining productivity-related outcomes.

Zahra and George (2002) have had a major influence on how absorptive capacity is viewed, linking the construct to a set of organisational routines and strategic processes through which firms acquire, assimilate, transform and apply knowledge with the aim of creating their dynamic organisational capacity. In particular, they divide absorptive capacity into potential (acquire, assimilate) and realised (transform and apply) absorptive capacity. Zahra and George (op. cit.) see these two components performing separate but complementary roles, whereby

[4] There are other directly observed proxies that have been used, such as patents (Zhang et. al., 2007); the domestic firm's size and the technology gap between a foreign firm and the domestic firm as an indicator of the domestic firm's absorptive capacity (Zhang et. al., 2010); the number of self-citations (Mancusi, 2004); and export status (Kim, 2015). In more macro-level studies, absorptive capacity has been proxied by the quality of government and the level of human capital (Becker et. al., 2013); entrepreneurial culture and the diversity of innovative activity at the city-region level (Mukherji and Silberman, 2013); levels of international trade, human capital, infrastructure quality, and quality of institutions and governance systems (Castellacci and Natera, 2013); and the level of human capital linked to importing capital with superior technology (Yasar, 2013). Hurtado-Ayala and Gonzalez-Campo (2015, Table 3) provide a more complete set of examples.

[5] Gambardella (1992) concluded that firms with better in-house scientific research programmes exploit outside scientific information more efficiently. Egbetokun and Savin (2014, p. 401) go further by arguing that "… a firm develops absorptive capacity not as a side effect of total R&D but by devoting a share of its total R&D budget explicitly to it". Thus (p. 403) they make a distinction between "absorptive R&D" (investments made to benefit from knowledge spillovers) and "inventive R&D" (the effort made by the firm to generate original knowledge).

some firms may have potential capacity but do not realise the benefits.[6] This approach has been challenged by Todorova and Durisin (2007), who argue that assimilation of knowledge takes place at the same time as its exploitation or application, without this knowledge having necessarily to be previously transformed in some way. Going further, it can be argued that realised absorptive capacity can only be empirically identified if the firm actually achieves some form of performance enhancement, and so trying to identify two separate components is problematic in practice. In much of the extant (mainly business) literature operationalising the concept of absorptive capacity, some studies follow Zahra and George (e.g. Camisón and Forés, 2010) while others prefer to define absorptive capacity as a single component (e.g. Cho, 2014).

(a) Approach used to measure absorptive capacity in the business literature

Those studies that follow the Zahra and George/Todorova and Durisin approaches try to identify, quasi-theoretically, the components of absorptive capacity rather than use a proxy like R&D and/or human capital for the construct (Camisón and Forés, 2010, Table 2, and Hurtado-Ayala and Gonzalez-Campo, 2015, Table 3, provide comprehensive examples of such approaches). That is, firms are typically asked to rank a series of statements relating to their self-assessed ability to search and obtain external information (acquisition), to use information internally (assimilation), to structure and link new information to existing knowledge (transformation), and to adapt existing technologies using new information (exploitation). Good examples of this type of approach are provided by Flatten et. al. (2015, Appendix A), Camisón and Forés (2010, Appendix A), and Cho (2014, Table 1). As an illustration, Table 1 shows the results obtained by Camisón and Forés (op. cit.) based on 952 Spanish firm responses in 2007; they asked firms to rank how well they did in each area relative to their competitors using a Likert scale ranging from 1 to 5, and then undertook factor analysis to obtain principal component indices capturing the latent variables potential and realised absorptive capacity.

Most other (recent) studies use a similar method to combine and represent the survey data collected. Clearly, this approach is based on accurately identifying the processes firms adopt

[6] For example, they argue that a firm may be able to identify, understand and assimilate external knowledge, but the firm may not be able to integrate such knowledge with its prior existing stock of knowledge (i.e. intangible assets). Camisón and Forés (2010, pp. 709-10) put the argument slightly differently; they state that "…although absorptive capacity can affect performance and competitive advantage through the exploitation of external knowledge, these effects require additional resources and capacities … such as innovation capacity". That is, they link potential and realised absorptive capacity with external learning capacity and internal learning capacity, respectively, with each "based on differentiated processes, routines and strategies".

in internalising external knowledge, linking them to separate components of absorptive capacity, and then adequately measuring them; it assumes that researchers have enough information to develop adequate statements capturing the processes, and that firms have the ability to consistently rank these statements in an objective and accurate manner.

Table 1: Factor loadings from PFA absorptive capacity model used by Camisón and Forés (2010)

Underlying questions[a]	Potential	Realised
Acquisition capacity		
Capacity to capture relevant, continuous and up-to-date information and knowledge on current and potential suppliers	0.353	
Degree of management orientation towards waiting to see what happens, instead of concern for and orientation towards their environment to monitor trends continuously and wide-rangingly and to discover new opportunities to be exploited proactively	0.628	
Frequency and importance of cooperation with R&D organisations – universities, business schools, technological institutes, etc. – as a member or sponsor to create knowledge and innovations	0.653	
Effectiveness in establishing programmes orientated towards the internal development of technological acquisition of competences from R&D centres, suppliers or customers	0.741	
Assimilation capacity		
Capacity to assimilate new technologies and innovations that are useful or have proven potential	0.621	
Ability to use employees' level of knowledge, experience and competencies in the assimilation and interpretation of new knowledge	0.637	
The firm benefits when it comes to assimilating the basic, key business knowledge and technologies from the successful experiences of businesses in the same industry	0.581	
Degree to which company employees attend and present papers at scientific conferences and congresses, are integrated as lecturers at universities or business schools or receive outside staff on research attachments	0.692	
Transformation capacity		
Capacity of the company to use information technologies in order to improve information flow, develop the effective sharing of knowledge and foster communication between members of the firm, including virtual meetings between professionals who are physically separate – Internet B2E portals, e-mail, teleworking etc.		0.734
Firm's awareness of its competencies in innovation, especially with respect to key technologies, and capability to eliminate obsolete internal knowledge, thereby stimulating the search for alternative innovations and their adaptation		0.694
Capacity to adapt technologies designed by others to the firm's particular needs		0.591
Degree to which firm prevents all employees voluntarily transmitting useful scientific and technological information acquired to each other		0.402
Application capacity		
The organisation's capacity to use and exploit new knowledge in the workplace to respond quickly to environment changes		0.321
Degree of application of knowledge and experience acquired in the technological and business fields prioritised in the firm's strategy that enables it to keep itself at the technological leading edge in the business		0.625
Capacity to put technological knowledge into product and process patents		0.643
Ability to respond to the requirements of demand or to competitive pressure, rather than innovating to gain competitiveness by broadening the portfolio of new products, capabilities and technology ideas		0.692

[a] For each question the respondent was asked to evaluate the strength of the firm's competitive position in relation to the average for direct competitors using a scale of 1 to 5.

(b) Approach used to measure absorptive capacity in the economics literature

In contrast, when using firm-level information economists generally prefer to use larger, more nationally representative data (often collected by government agencies) that is more objective since surveyed firms are asked to state if certain activities are taking place (rather than, as in Table 1, rank their self-assessed ability to search, obtain and use information and adapt existing technologies using such new information); and it is more generalizable since it is obtained from large datasets covering many countries and often for significant time periods. For example, Harris and Li (2009), used one wave of nationally representative data from the establishment-level Community Innovation Survey (CIS) that has been carried out in the UK (and other EU Member States) by the Office for National Statistics (and other relevant EU members' government agencies) over several years. This is a well-used dataset in both the economics and business strands of the literature; the advantage of using such CIS data is that firms are asked to report information on key elements of organisational learning and networking processes that can be related to absorptive capacity, i.e. external sources of knowledge or information used in innovation activities and their importance[7]; partnerships with external bodies on innovation co-operation[8]; and the introduction of changes in business practices[9]; all of which can be related to external knowledge spillovers and internal capabilities and thus aspects of absorptive capacity. To illustrate this economics-type approach to measuring absorptive capacity, here we use data from CIS4 – for 2002-2004 – through to CIS9 – covering 2012-2014. Different from Harris and Li (2009), we use multiple waves of CIS and measure absorptive capacity based on a longitudinal dataset. Therefore, we are not only able to measure absorptive capacity benefiting from using CIS data, to identify which firms have higher absorptive capacity, what firm characteristics are associated with higher absorptive capacity and how absorptive capacity impacts on productivity-enhancing activities, but also we are able to identify whether this

[7] See Q.16 in the CIS questionnaire where firms are asked to rank the importance to innovation activity of information from several sources starting with suppliers, customers, and competitors through to technical publications. Respondents were asked to rank each factor (from not used to high importance). (https://www.gov.uk/government/collections/community-innovation-survey.)

[8] See Q.17 in the CIS questionnaire where firms state if they cooperated with suppliers, customers, competitors, through to research institutes at the following locations: 'UK local', 'UK national', 'European', 'or in 'Other' countries. From this we could identify cooperation (coded 1 if present, 0 otherwise) at the national (which also includes local) and international level.

[9] See Q.3 in the CIS questionnaire. These are measured by the implementation of new business practices for organising procedures (e.g., business improvement methods); new methods of organising work practices; new methods of organising external relationships; or implementation of changes to marketing concepts or strategies. When an activity too place it was coded as 1 (0 otherwise).

Table 2: (Weighted) SEM model of absorptive capacity, GB, 2004-14

Standardized	$\hat{\beta}$	Z-value
Structural		
External knowledge <- Absorptive capacity	0.829	123.8
National cooperation <- Absorptive capacity	0.653	92.8
International cooperation <- Absorptive capacity	0.269	18.9
Specialised knowledge <- Absorptive capacity	0.511	47.0
Business innovation <- Absorptive capacity	0.784	96.0
Measurement		
Suppliers <- External knowledge	0.679	142.8
Clients/customers <- External knowledge	0.770	161.2
competitors <- External knowledge	0.697	132.1
Conferences/trade fairs/exhibitions <- External knowledge	0.639	123.9
Scientific journals and trade/technical publications. <- External knowledge	0.610	97.6
Professional/industry associations <- External knowledge	0.676	128.4
Technical/industry standards <- External knowledge	0.691	146.3
Suppliers (national) <- National cooperation	0.716	103.1
Clients/customers (national) <- National cooperation	0.757	131.9
Competitors (national) <- National cooperation	0.665	82.9
Consultants/labs/R&D institutes (national) <- National cooperation	0.642	70.0
Universities and other HEIs (national) <- National cooperation	0.566	56.9
Government/research organisations (national) <- National cooperation	0.576	55.2
Suppliers (international) <- International cooperation	0.474	31.9
Clients/customers (international) <- International cooperation	0.514	35.2
Competitors (international) <- International cooperation	0.628	36.2
Consultants/labs/R&D institutes (international) <- International cooperation	0.741	49.8
Universities and other HEIs (international) <- International cooperation	0.819	53.7
Government/research organisations (international) <- International cooperation	0.808	49.1
Consultants/labs/R&D institutes <- Specialised knowledge	0.873	45.7
Universities and other HEIs <- Specialised knowledge	0.690	56.6
Government/research organisations <- Specialised knowledge	0.720	79.4
New business practices <- Business innovation	0.584	78.4
New work practices <- Business innovation	0.586	90.3
New external relations <- Business innovation	0.629	97.6
New marketing strategies <- Business innovation	0.640	105.9
Export <- Absorptive capacity	0.262	35.2
R&D <- Absorptive capacity	0.641	109.2
Innovation <- Absorptive capacity	0.571	42.5
(unweighted) N	78,938	
Log pseudo-likelihood	2144436.7	

Standard errors adjusted for 48,380 clusters in establishment identifier. 25 covariances between endogenous variables modelled but not reported. Also estimates of the constant for each endogenous relationship is not reported

measurement approach of absorptive capacity is reliable across different waves of surveys. Using factor analysis, Table A.1 (in the appendix) shows the results based on pooled data from CIS4-9 (the results from each survey period are very similar, confirming the validity of the approach); the numbers in the first five columns of data show the correlations (greater than 0.5) between the principle component factors extracted (these are continuous variables with a mean of 0 and standard deviation of 1 and comprise measures of absorptive capacity capturing the establishment's capacity to exploit external sources of knowledge; build up partnerships with other enterprises or institutions at both the national and international level; the use of specialised knowledge from research organisations; and implement new organisational structures and HRM strategies) and the underlying data from which they are derived. The factor analysis was then confirmed by estimating a structural equation model, which also included 25 covariances between the endogenous variables modelled. The results are presented in Table 2[10] (Table S.2 in the unpublished appendix provides the equation-level goodness of fit statistics for the SEM model; the overall model R^2 is 0.87 suggesting the model is appropriately specified). In terms of the results from the SEM model and the approach based on factor analysis, the correlation between each individual index of absorptive capacity is high for 'external knowledge' and 'national cooperation' (around 0.96 – see the figures in italics in Table S.3); however, other indices have much lower correlation coefficients (e.g., 0.18 for 'international cooperation'). The absorptive capacity indices based on the SEM model are preferred, since they allow for a residual term in constructing each latent variable, and they also consider covariances between endogenous variables. Based on the SEM model, the correlation between each individual index and the overall index of absorptive capacity (derived from the underlying indices – see the structural part of the model in Table 2) is 0.92, 0.76, 0.37, 0.65 and 0.89 for 'external knowledge' 'national cooperation', 'international cooperation', 'specialised knowledge' and 'business innovation', respectively (see Table S.3).

(c) Comparison of the two approaches

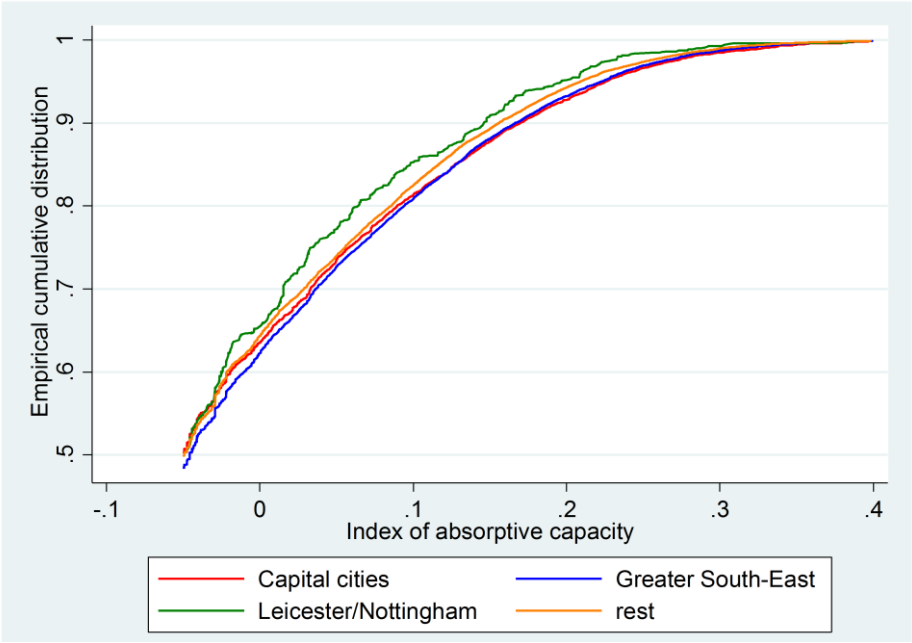
Generally, there is common ground in the literature as to what researchers are trying to measure, taking into account the problems encountered since absorptive capacity is a latent concept. Instead, differences arise with regard to how it should be measured. Economists are

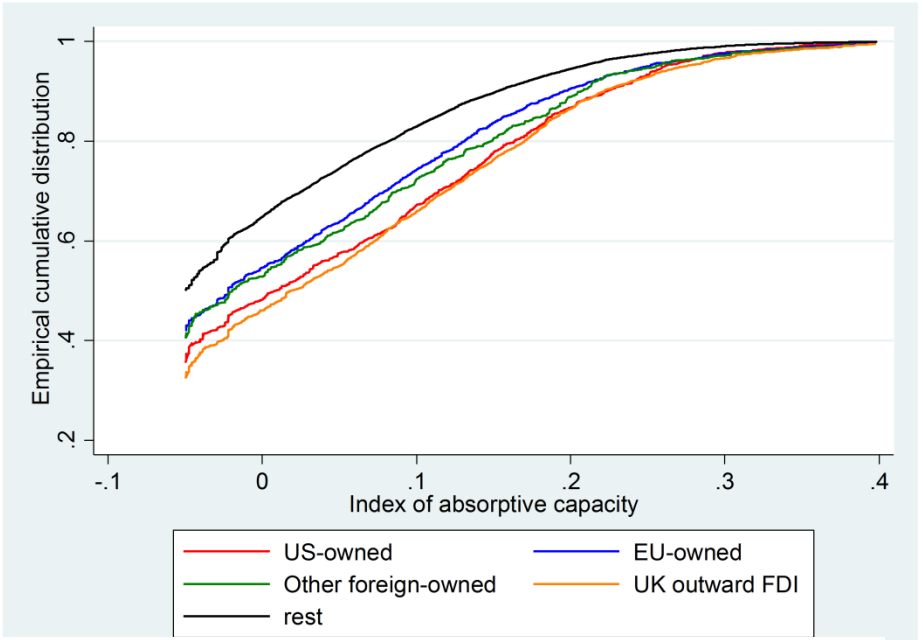
[10] Again estimating the model based on data from each survey period produces very similar results. Note also, the SEM maps the impact of the overall index of absorptive capacity on (0/1) dummy variables that indicate whether the establishment exported, undertook R&D or innovated, showing that there was a strong relationship (especially for doing R&D and innovating).

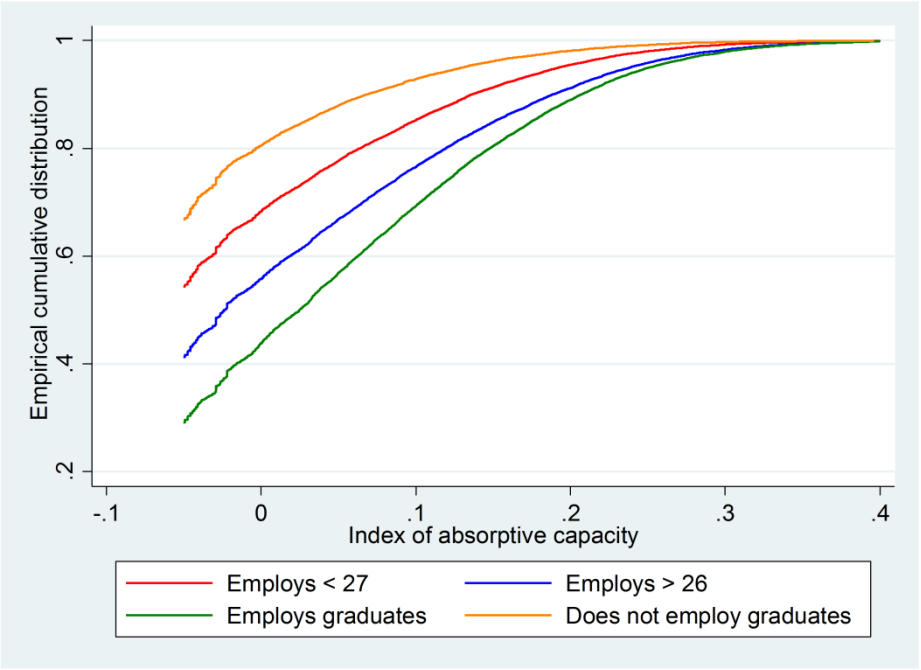
cautious when undertaking empirical research relying on subjective data, as Bertrand and Mullainathan (2001) argued when they discussed its use noting "… this is one data source that economists rarely use (marking) an important divide between economists and other social scientists … they doubt whether (subjective) questions elicit meaningful answers" (p. 67). The main drawbacks of using data based on respondents' answers to subjective questions (such as those set out in Table 1) has been extensively discussed by especially psychologists (cf. Schwartz, 1999). Bertrand and Mullainathan (op. cit.) discuss how responses are affected by the ordering of questions (and thus the content of adjacent questions); that respondents often make little mental effort in answering questions and when they do they may not have an answer in a coherent or correct form. Schwatrz (op. cit.) discusses issues with 'understanding the question' especially with respect to what the researcher is looking for. And "once respondents have determined the intended meaning of the question, they face additional tasks … (including) the recall of relevant information from memory, the computation of a judgment, and the formatting of these judgments in line with the response alternatives provided by the researcher" (p. 97). The information sought by Camisón and Forés (2010) – as set out in Table 1 – required detailed knowledge (by both the researcher and respondent) of a range of aspects of the often tacit processes underlying how a business operates, all benchmarked against competitors, which suggests that respondents are forced into 'estimation strategies' often which involves "… individuals … (truncating) the search process as soon as enough information has come to mind to form a judgment with sufficient subjective certainty. Accordingly, the judgment is based on the subset of potentially relevant information that is most accessible at the time of judgment" (Schwartz, op. cit., p. 100). Moreover, questions are often answered by either CEOs, managers or HR managers (e.g., Chang et al., 2014). Judgement from managers in different positions of an organisation may hold different views on these subjective questions; the information obtained from respondents is likely to depend on who in the firm takes part in the survey. Furthermore, the use of Likert scales is also often an issue, with respondents often heavily concentrating on one response side (agree/disagree), avoiding the extreme options on the scale because of the negative implications involved (even if extreme choices are most accurate) – see, for Hartley (2013), for a wider discussion of Likert-type scales.

In comparison, the CIS survey data (widely used by economists) are more objective, as it mainly asks respondents whether the firm engaged in certain activities (yes/no), although there are instances where Likert scales are used to rank the importance of certain types of information (from 'not used' to 'high importance'). At worse, the CIS survey asks respondents to provide

Figure 1: (Weighted) Absorptive capacity indices by various firm characteristics, Great Britain, 2004-2014







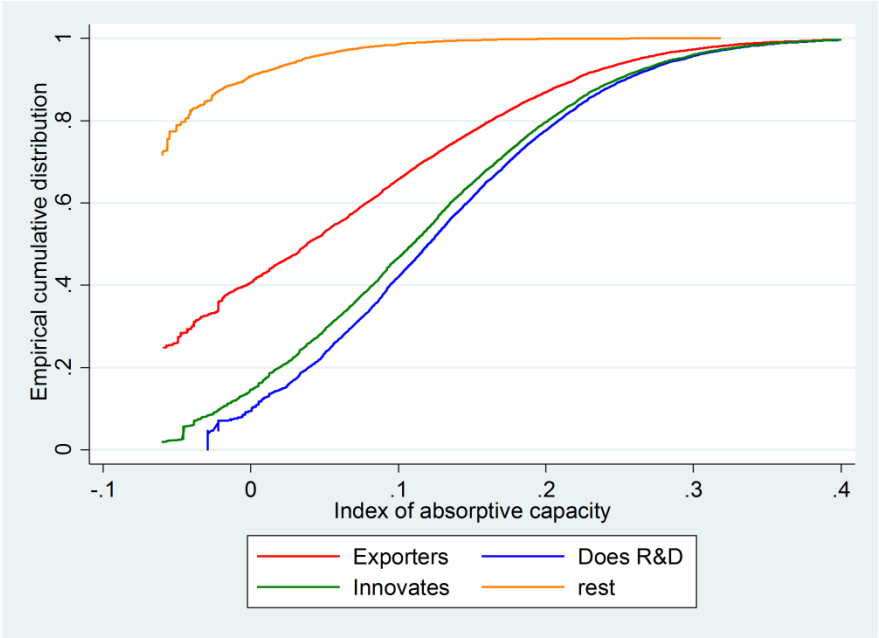
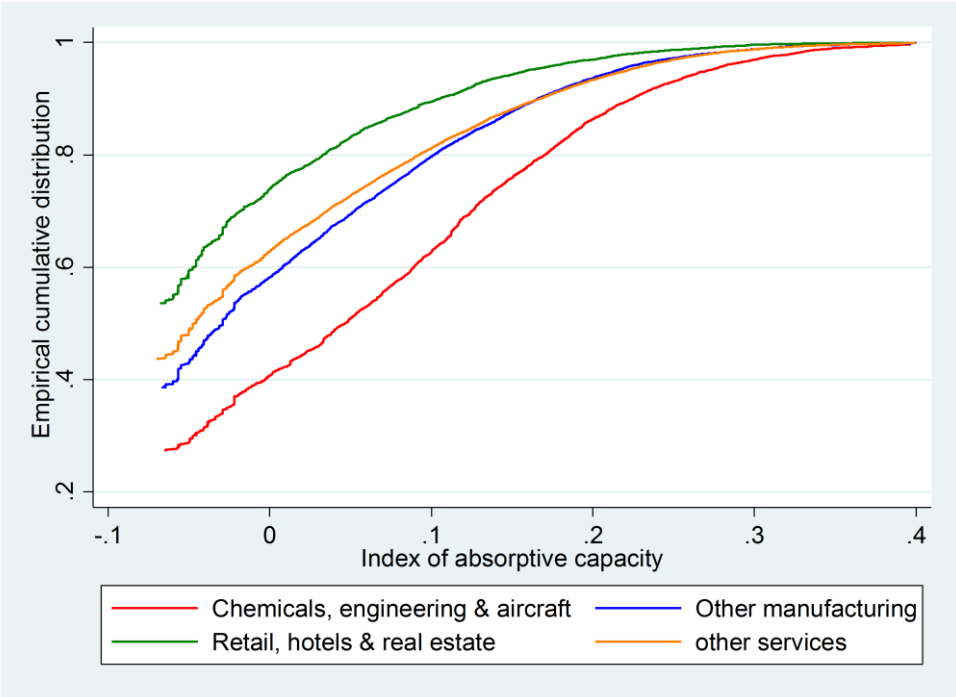


Figure 1: (cont.)



(semi-) subjective answers to objective statements; whereas the type of questions typically asked in the business literature usually comprise subjective responses to subjective questions. However, the apparent strength of using CIS data is counterbalanced by what most would see as a weakness (inherent in the use of secondary data not specifically designed for the research purpose to which the data are put); that the economists' approach is not generally about explaining the process – the theoretical antecedents – generating the latent variable(s), but rather the more practical outcome of obtaining proxies for measuring absorptive capacity, based on how and to what extent firms are able to internalise external knowledge and information, that are then used to explain (inter alia) business performance.

3. Which firms have higher levels of absorptive capacity and is it persistent over time?

To set the scene, Figure 1 shows the cumulative distribution of the absorptive capacity index (obtained from the SEM model) separately for firms with a range of different characteristics. Establishments located in the Greater South East of England (which covers the administrative regions of the South East, Eastern England, London and the South West) generally have higher absorptive capacity throughout (their distribution lies to the right of the distributions of other areas); followed by capital cities (London plus Cardiff and Edinburgh); and then other areas (excluding Leicester and Nottingham which have the lowest levels of absorptive capacity).

Table 3: (weighted) Ordered probit of determinants of absorptive capacity, GB, 2004-14 (marginal effects reported)

	manufacturing				services			
VARIABLES	$\frac{\partial p(AC<-0.04)}{\partial x}$	$\frac{\partial p(-0.04<AC<0.04)}{\partial x}$	$\frac{\partial p(0.04<AC<0.13)}{\partial x}$	$\frac{\partial p(AC>0.13)}{\partial x}$	$\frac{\partial p(AC<-0.08)}{\partial x}$	$\frac{\partial p(-0.08<AC<-0.03)}{\partial x}$	$\frac{\partial p(-0.03<AC<0.07)}{\partial x}$	$\frac{\partial p(AC>0.07)}{\partial x}$
time	0.018***	-0.001***	-0.005***	-0.011***	0.017***	-0.001***	-0.006***	-0.010***
27-82 employees	-0.032***	0.003***	0.010***	0.020***	-0.019**	0.001**	0.006**	0.011**
83-256 employees	-0.057***	0.005***	0.017***	0.035***	-0.030***	0.002***	0.010***	0.018***
257+ employees	-0.093***	0.008***	0.028***	0.058***	-0.076***	0.006***	0.025***	0.045***
1-5% graduates employed	-0.202***	0.017***	0.060***	0.124***	-0.153***	0.011***	0.051***	0.091***
6-20% graduates employed	-0.238***	0.020***	0.071***	0.147***	-0.191***	0.014***	0.063***	0.113***
21-50% graduates employed	-0.293***	0.025***	0.088***	0.180***	-0.239***	0.018***	0.080***	0.142***
51+% graduates employed	-0.273***	0.023***	0.082***	0.168***	-0.274***	0.020***	0.091***	0.163***
Age of establishment	–	–	–	–	0.002***	-0.000***	-0.001***	-0.001***
Single-plant enterprise	–	–	–	–	-0.025***	0.002***	0.008***	0.015***
Diversification	0.076***	-0.006***	-0.023***	-0.047***	0.054***	-0.004***	-0.018***	-0.032***
Herfindahl index	0.064*	-0.005*	-0.019*	-0.040*	–	–	–	–
Links with HEI	-0.433***	0.037***	0.130***	0.267***	-0.519***	0.038***	0.173***	0.308***
UK-owned outward FDI	–	–	–	–	-0.023*	0.002*	0.008*	0.014*
EU-owned	0.048***	-0.004***	-0.015***	-0.030***	–	–	–	–
Birmingham	-0.047**	0.004**	0.014**	0.029**	–	–	–	–
Bristol	–	–	–	–	-0.077***	0.006***	0.026***	0.046***
Glasgow	-0.121***	0.010***	0.036***	0.074***				
Leicester	–	–	–	–	0.087**	-0.006**	-0.029**	-0.052**
Nottingham	-0.083*	0.007*	0.025*	0.051*	0.088***	-0.007***	-0.029***	-0.052**
Greater South-east	–	–	–	–	-0.031***	0.002***	0.010***	0.018***
East Midlands	0.026**	-0.002**	-0.008**	-0.016**	-0.041*	0.003*	0.014*	0.024*
North East	0.039***	-0.003***	-0.012***	-0.024***	–	–	–	–
North West	0.021*	-0.002*	-0.006*	-0.013*	–	–	–	–
Scotland	0.059***	-0.005***	-0.018***	-0.036***	–	–	–	–
South West	0.038***	-0.003***	-0.011***	-0.023***	–	–	–	–
Wales	0.033**	-0.003**	-0.010**	-0.020**	–	–	–	–
West Midlands	0.040***	-0.003***	-0.012***	-0.024***	–	–	–	–
Yorks-Humberside	0.032***	-0.003***	-0.010***	-0.020***	–	–	–	–
Industry dummies	yes	yes	yes	yes	yes	yes	yes	yes
Observations	19,709				49,457			

Definitions of variables are provided in Table A.2. A table with standard errors (and the results for the industry dummies) is available on request. ***/**/* indicates significance levels at the 1/5/10% levels.

The second panel shows that multinational firms do must better as well, especially establishments that belong to UK multinationals, followed by US-owned firms. Establishments employing graduates have significantly better absorptive capacity levels, as well as those that are relatively larger, innovators (product and/or process), those engaged in R&D, and to a lesser extent exporters. Establishments involved in the chemicals, engineering and aircraft sectors perform the best, followed by other manufacturing, and other services (excluding retail, hotels and real estate).

These results are as expected; a wider set of results based on what determines absorptive capacity using a more detailed set of establishment-level characteristics are presented in Table 3. Separately for manufacturing and services, absorptive capacity was divided into quartiles[11] and (stepwise) ordered probit models were estimated, to provide an indication of which factors are most highly correlated with absorptive capacity (Table A.2 provides definitions of the variables used, together with some descriptive statistics). Over time, there has been a general decline in absorptive capacity (in both manufacturing and services); relative to the benchmark sub-group (establishments employing less than 27 employees), larger establishments had higher absorptive capacity (for example, employing 257+ employees increased the likelihood of being in the highest absorptive capacity quartile by 5.8% and 4.5%, in manufacturing and services, respectively). Employing a larger proportion of graduates was also associated with the highest levels of absorptive capacity (e.g., 16-17% higher in both sectors when 51+% of employees held a degree). The age of the establishment was only important in services, with age associated with lower absorptive capacity. Being a single-plant enterprise increased the probability of belonging to the highest absorptive capacity sub-group by (cet. par.) 1.5%, in services. Being in an area with a higher level of R&D stock diversification was associated with lower absorptive capacity, in both sectors; higher levels of industry concentration of sales in an industry also was linked to lower absorptive capacity, but only in manufacturing. Having a link with a university significantly boosted the probability of having the highest levels of absorptive capacity (by 27-31%, depending on the sector).

Belonging to a UK-owned multinational was (cet. par.) associated with higher absorptive capacity in services (but not manufacturing), while EU-owned establishments were less likely to belong to the highest absorptive capacity sub-group in manufacturing. In manufacturing, and

[11] The distribution of absorptive capacity is highly non-normal, and therefore OLS regression was not a feasible option. The Sharpiro-Wilk W test for normality of the index produced a W (V) value of 0.924 (1978.4), with an associated *z*-value of 21.21.

relative to other major cities, establishments in Birmingham, Glasgow and Nottingham were more likely to experience high absorptive capacity; in services, those located in Bristol did better, but establishments in Leicester and Nottingham underperformed (see Figure 1). Relative to the South East, London and Eastern regions, establishments in manufacturing located in other regions were (cet. par.) likely to have relatively lower levels of absorptive capacity; similarly, in services, the Greater South East and the East Midlands did better vis-à-vis other regions.

Table 4: Transition matrix for absorptive capacity (cells show row percentage of establishments)

	Quintile of absorptive capacity (t+1)					
Quintile (t)	1	2	3	4	5	Total
1	54.4	6.5	17.5	12.9	8.6	100
2	20.6	35.5	15.3	16.0	12.5	100
3	34.9	10.1	21.5	20.6	12.9	100
4	25.6	8.9	16.7	27.8	21.1	100
5	14.7	6.7	9.8	18.6	50.2	100
Total	30.6	9.8	15.5	19.4	24.7	100

Source: index of absorptive capacity obtained from Table 2

Table 5: (Weighted) OLS regression of absorptive capacity (AC) on its lagged value

	$\hat{\beta}$	$\hat{\beta}$	$\hat{\beta}$	$\hat{\beta}$	$\hat{\beta}$
AC_{t-1}	0.495				
	(42.14)				
AC_{t-2}		0.432			
		(24.91)			
AC_{t-3}			0.362		
			(21.00)		
AC_{t-4}				0.278	
				(11.59)	
AC_{t-5}					0.274
					(7.43)
(unweighted) N	25,417	12,372	5,224	3,433	1,644

t-values in parenthesis. Source: index of absorptive capacity obtained from Table 2

Having examined which types of establishments did better in terms of absorptive capacity, this section extends the approach used by Harris and Li (2009) by looking at whether those with high (low) absorptive capacity maintained their relative position in the distribution over time. Firstly, Table 4 reports the transition matrix across 2004-2014 based on grouping establishments by absorptive capacity quintiles. The diagonal shows that establishments in most quintiles had a high probability of remaining in that quintile over time (e.g., 54.4% in the lowest quintile did not move, while over 50% in the highest remained in the same sub-group),

or only moving up or down one sub-group. This suggests a considerable degree of stability over time, showing that it takes a considerable period to build absorptive capacity (or to see it erode). Table 5 produces similar evidence based on regressing absorptive capacity in time *t* on its lagged values; again, establishments tend to remain with high (low) absorptive capacity for long periods.

4. How important is absorptive capacity in determining productivity drivers?

In this section, the absorptive capacity indices obtained from the SEM are used as determinants of whether an establishment exported, innovated (product and/or process), or undertook any R&D. The (weighted) CIS data covering 2004-2014 is used, and (stepwise) random-effects probit models are estimated that include lagged values of the dependent variables and by treating absorptive capacity as predetermined. The latter is justified on both theoretical and empirical grounds that absorptive capacity is a dynamic capability that it takes time for a firm to build-up. Theory is based on a resource-based view of the firm; Teece and his colleagues – see Teece et. al. (1997); Teece and Pisano (1998) – argue that these capabilities are the sub-set of its competences and capabilities that allow the firm to create new products and processes and to respond to changing market conditions; they are the core of its competitiveness. The competitive advantage of firms rests on processes of coordinating and combining assets, shaped by the firms' (prior) knowledge asset positions, as well as path dependencies in asset acquisition and development. Fundamentally, Teece and other proponents of the resource- and knowledge-based views of the firm argue that such competencies and capabilities by their very nature cannot be bought; they can only be built by the firm.[12] The empirical evidence was in part presented above in Tables 4 and 5 showing the persistence of absorptive capacity over time. Note, however, later we provide some robustness checks to ensure our results are not biased due to potential endogeneity of absorptive capacity.

Including both direct measures of absorptive capacity and lagged values of the dependent variables (i.e., exporting, innovation, and R&D) is in part recognising there are different processes underlying the firm's ability to engage in productivity enhancing activities. In line with Camisón and Forés (2010) we are allowing absorptive capacity to directly impact through

[12] That is, they cannot easily be acquired, replicated, diffused, or copied – they therefore cannot easily be transferred or built-up outside the firm. This in part is due to the key role that learning plays both in enabling the firm to align and thus exploit its resources, competencies and capabilities, and in allowing the firm to internalise outside information into knowledge; and the way the firm learns is not acquired but it is determined by its unique 'routines', culture and its current position (i.e., stock of – tacit – knowledge).

acquiring and assimilating external knowledge, while lagged values of R&D, innovation and exporting reflect past investments in building capabilities (i.e., prior accumulated competencies) and thus the ability to overcome the sunk cost barriers associated with such activities.

Essentially, in Table 6 the equations estimated are reduced-form; while there is a valid case for including contemporaneous values of the productivity-enhancing activities covered, such current values of exporting, innovation and R&D requires modelling a simultaneous probit system (see Harris and Moffat, 2011).[13] Here the goal is to emphasise how influential absorptive capacity is in determining these activities.

Table 6 produces the results, separately for manufacturing and services. The pseudo-R^2 values obtained are high for this type of model, suggesting they are well-specified. The value of the lagged values in each model show how important fixed and sunk costs (and thus prior stocks of knowledge) are in determining productivity-enhancement. Thus, establishments that exported last period were some 32-37% more likely to export in *t* in manufacturing and services. Interestingly, past innovation and/or R&D both tend to impact on current decisions to innovation/undertake R&D, but surprisingly the impacts are much smaller when compared to lagged exporting impacts. The key variables in Table 6 relate to the impact of absorptive capacity. Table 7 shows the impact of a change in absorptive capacity from the value experienced by the median firm to the value that defines the start of the 99 percentile. The latter are more informative than the marginal effects produced in Table 6[14], and we concentrate on them here, because they effectively relate to the impact of moving an average firm in a sector to the frontier value of each measure of absorptive capacity. The effect of external knowledge spillovers is particularly strong in determining innovation and R&D activities. An increase in external knowledge increases the probability of exporting, innovation and R&D by 13.6, 47.2, and 40 percentage points, respectively, in manufacturing; given the average propensity to export, innovate and undertake R&D was 53.8%, 40.1% and 39.9%, respectively, these are substantial increases. The impact of national cooperation is weaker (no impact on exporting), but still important for innovation and R&D (particularly in manufacturing). International

[13] A simultaneous probit system estimate is econometrically complicated, so instead right-hand-side values of $exporting_t$, $innovation_t$, and $R\&D_t$ are substituted out using the exogenous variables determining each activity.
[14] Table 6 is based on the default output from using the *margins* command in Stata (which is effectively the marginal effect of increasing standardised absorptive capacity by one standard deviation i.e., the effect of adding 1 to the current value).

Table 6: (Weighted) Estimates of (stepwise) random-effects probit models determining exporting, R&D and innovation, GB, 2004-2014 (by sector) – marginal effects reported

	Manufacturing			Services		
	Exporting	Innovation	R&D	Exporting	Innovation	R&D
$R\&D_{t-1}$	–	–	0.152***	–	0.025***	0.099***
$innovation_{t-1}$	–	0.150***	0.017***	–	0.098***	0.013***
$export_{t-1}$	0.371***	–	0.053***	0.318***	0.026***	0.028***
External knowledge[a]	0.046***	0.134***	0.107***	0.028***	0.097***	0.079***
National cooperation[a]	(0.003)	(0.003)	(0.003)	(0.001)	(0.001)	(0.001)
International cooperation[a]	–	0.065***	0.025***	–	0.035***	0.017***
Specialised knowledge[a]		(0.002)	(0.002)		(0.001)	(0.001)
Business innovation[a]	–	–	–	0.005***	–	–
15-26 employees	0.031***	0.029***	–	0.027***	–	–
27-82 employees	0.046***	0.043***	–	0.034***	–	–
83-256 employees	0.042***	0.062***	–	0.035***	–	–
257+ employees	–	0.050***	0.023***	0.054***	–	0.013***
No graduates employed	-0.111***	–	-0.075***	-0.076***	–	-0.046***
6-20% graduates employed	–	0.026***	–	–	–	–
21-50% graduates employed	0.081***	0.039***	0.040***	0.031***	–	–
51+% graduates employed	–	–	–	0.059***	–	0.024***
ln (age)	0.020***	–	–	0.009***	0.006***	–
Multi-region enterprise	–	–	–	0.020***	0.018***	–
Single-plant enterprise	–	–	–		0.014***	–
ln (capital-labour ratio)	–	–	–	0.005***		0.004***
UK-owned outward FDI	0.040***	–	–	0.060***	–	–
US-owned	0.120***	–	–	0.045***	–	–
EU-owned	0.058***	–	–	0.073***	–	-0.030***
Other foreign-owned	0.092***	–	–	0.092***	–	–
Links with HEI	0.033***	0.037***	0.023***		0.043***	0.014***
ln (Herfindahl index)	–	–	–	0.009***	–	-0.007***
ln (industry agglomeration)	0.004***	–	–	0.004***	–	–
ln (diversification)	–	–	–	-0.014***	–	–
ln (Enterprise employment)	–	-0.006***	-0.006***	-0.012***	-0.006***	–
Aberdeen	–	–	–	0.091***	-0.047***	
Bristol	–	-0.118***	0.096***	-0.053***	–	–
Edinburgh	–	–	–	0.054***	–	–
Leicester	–	-0.061***	–	–	-0.110***	–
Liverpool	–	–	–	-0.114***	-0.091***	–
Manchester	–	0.115***	–	–	–	–
Sheffield	–	–	-0.107***	0.053***	–	–

Greater South-east	–	–	–	0.020***	–	–
East Midlands	–	–	–	0.022***	–	-0.017***
North East	-0.043***	–	–	–	-0.031***	
Scotland	–	–	–	–	–	-0.025***
Wales	–	–	–	–	-0.027***	–
2008	0.083***	-0.037***	-0.087***	0.075***	-0.067***	-0.056***
2010	0.148***	0.045***	-0.109***	0.070***	–	-0.106***
2012	–	–	-0.147***	–	-0.038***	-0.114***
2014	0.084***	–	-0.135***	0.057***	-0.027***	-0.106***
2-digit industry dummies	yes	yes	yes	yes	yes	yes
Observations	6,874	6,874	6,874	15,266	15,266	15,266
No. of enterprises	4,451	4,451	4,451	9,909	9,909	9,909
Pseudo log-likelihood	-23846.012	-27963.775	-23832.543	-63753.279	-67253.843	-56905.503
Pseudo-R^2	0.459	0.356	0.446	0.412	0.375	0.433

[a] These variables in Table A.2 have been standardised (mean subtracted and divided by standard deviation).

Definitions of variables are provided in Table A.2. A table with standard errors (and the results for the industry dummies) is available on request. ***/**/* indicates significance levels at the 1/5/10% levels.

Table 7: Marginal effects of absorptive capacity (the median value to the 99 percentile) on exporting, innovation and R&D in GB, 2004-2014 (by sector)

	Manufacturing			Services		
	Exporting	Innovation	R&D	Exporting	Innovation	R&D
External knowledge	0.136***	0.472***	0.400***	0.099***	0.543***	0.436***
National cooperation	–	0.349***	0.128***	–	0.223***	0.091***
International cooperation	–	–	–	0.039***	–	–
Specialised knowledge	-0.072***	-0.216***	-0.123***	-0.056***	-0.140***	-0.071***
Business innovation	0.042***	0.268***	0.384***	0.055***	0.376***	0.424***
Mean(weighted) value of dependent variable	0.538	0.401	0.399	0.251	0.227	0.217

Source: Table 6 and Table A.2. *** p<0.01, ** p<0.05, * p<0.1

cooperation has little to no impact – which in part reflects the low value of the index for most establishments (Table A.2) with relatively little variation between them. UK establishments generally do not engage as much in this form of gaining absorptive capacity. The impact of business innovation for innovation and R&D is much more significant, and it is even more important in services vis-à-vis manufacturing. The unexpected result is the impact of establishments gaining specialised knowledge from research institutions based in the UK; there is, cet. par., a relatively large negative impact on especially innovation (and to a smaller extent R&D). The negative impact of specialised knowledge is mainly due to two reasons: the relative weakness of this particular knowledge source and the way this knowledge is used. Specialised knowledge is obtained from HEI's, consultants, labs, government and research organisations and unlike more influential actors in supply network (e.g. clients, suppliers), these organisations have little power to force establishments to implement different practices (Ireland and Webb 2007). Additionally, the specialised knowledge from consultants and government is often used to assess whether establishments' practices have met industry standards and/or adhere to updated health and safety regulations. Inertia and risk aversion have a substantial impact on the firm's willingness to change (Hannan and Freeman, 1984). When establishments learn that they have achieved, or have even gone beyond, industry standards and legal regulations, it is unlikely for them to change their practice further but rather withdraw prior practices involving changes. And secondly, while (certain elements of) the specialised knowledge from HEI's, labs and research organisations can be used to help firms to adopt frontier technologies, establishments cannot easily internalise this specialised information, because public research knowledge is hard to transfer into "ready-to-produce" innovations (Mueller 2006, p.1502). The gap between specialised knowledge and practical innovations may mean that the more establishments try to reduce the gap, the greater the negative impact.[15]

To test for robustness, the results in Table 7 were also reproduced using two alternative approaches. Firstly, whilst we have argued (and presented evidence) that the measures of absorptive capacity can be considered as pre-determined variables (see the beginning of this sub-section), we have re-estimated the random effects probit models using a one-for-one 'matching' approach with 'treated' firms being those with absorptive capacity (based on the overall index) in the top 50% and a 'control' sub-group comprising those with similar characteristics to the 'treated' (e.g., size, ownership, location, age) but with absorptive capacity

[15] This finding is consistent with the fact that EU firms do worse to commercialize specified knowledge generated in universities and research institutions than their U.S. counterparts (EC 2001; Arundel and Geuna 2004).

values below the median. The results from the 'matching' model therefore help to mitigate against selectivity bias that could arise if the characteristics of firms with high absorptive capacity also 'push them' into productivity enhancing activities (exporting, innovating and undertaking R&D).

The second model recognises the likely upward bias in the lagged dependent variables of the dynamic models estimated, due to the 'initial conditions problem' associated with the correlation between initial exporting, innovation and R&D (i.e., $export_0$, $innovation_0$ and $R\&D_0$) and the other variables in each equation. Wooldridge (2005) suggests a simple solution is to include $export_0$, $innovation_0$ and $R\&D_0$ in the models estimated. The results from 'matching' and the Wooldridge approach are presented in Table A.3 in the appendix[16], and suggest that the baseline results (Table 7) are generally robust to different modelling approaches (the results from matching are generally smaller – particularly in manufacturing – due to the fact we are concentrating more on firms with characteristics associated with higher levels of absorptive capacity; the 'Wooldridge' results are very similar to those presented in Table 7).

Lastly, we briefly consider the impact of other variables included in the model (cf. Table 6), which proxy for various other factors determining the dependent variables, including a firm's wider knowledge base and capabilities. Larger establishments are usually more likely to engage in exporting (and innovation in manufacturing), but size effects are less important in services especially in determining whether R&D is undertaken. Having (more) graduates is usually positive, and older establishments are more likely to export (but age, cet. par., has no discernible effect on innovation activities). Multi-region and single-plant enterprises in services do better in terms of the probability of exporting or innovating (this is relative to multi-plant single region enterprises); a higher capital-labour ratio also benefits service sector innovation.

Being foreign-owned (especially US-owned) benefits exporting, and links with universities increases productivity more generally (cf. Harris et. al., 2013, for further evidence using CIS). Exporters of services benefit from belonging to industries with high industry concentration, while the industrial concentration of R&D across travel-to-work areas (TTWAs) also boosts the propensity to export. In contrast, having a diversified R&D stock across TTWAs lowers exporting activity in services. Cet. par., larger enterprises are less likely to engage in the

[16] The full results are presented in the unpublished appendix Table S.4.

activities covered. Location in certain major cities and regions is important, without any clear-cut patterns emerging. Lastly, relative to 2002-04 and 2010-12, exporting was higher in other years, while relative to 2002-04 the probability of doing R&D (cet. par.) was much lower (e.g., 9-15% in manufacturing).

In summary, relative to these other impacts, Tables 6 and 7 show that absorptive capacity as measured here – net of the impact of foreign-ownership and human capital (proxied by the percentage of graduates employed) – has a substantial influence on exporting, innovation and undertaking R&D, and thus consequently firm-level productivity.

5. Is there a role for government in increasing absorptive capacity?

The above results show the importance of absorptive capacity to firms in terms of R&D, exporting and innovation, leading to the question of how industrial policy can help firms in this area, so improving the overall productivity performance of the economy. There have been recent shifts away from placing the firm (and the need to ensure it has sufficient absorptive capacity) at the centre of the policy debate; there is now a much greater emphasis on networks as a means to foster greater innovativeness in particularly smaller firms (Jacobsson and Bergek 2011). This is not new, as Bougrain and Haudeville (2002) showed when discussing the preference in the OECD for network promotion policies over those that provide direct financial assistance. Thus policy tends to centre more on technology infrastructure; as Metcalfe and Georgiou (1997) stated: "recognition of the complex systems characteristics of the innovation process takes us to a different rationale for policy, a rationale which recognises the ambiguity and uncertainty of the policy environment and the futility of picking winners as distinct from encouraging winners to emerge by strengthening the innovation process in general… from the system perspective, it follows that individual firms are unlikely to be the focus of policy, rather the emphasis will be… upon all the co-operating groups of institutions defining a particular innovation system". Building-up the technology infrastructure system is the central focus of the innovation process (cf. the 'pillars' and 'foundations' underpinning the current approach in the UK to industrial strategy – BEIS, 2017a,b).

However, it can be argued that the policy debate should indeed emphasise the central role of the firm based on at least two reasons: first, firms are more efficient at exploiting (tacit) knowledge and thereby building intangible assets. In particular tacit knowledge is transferred more efficiently inside the firm rather than outside. This is because tacit knowledge is "sticky"

to where it resides and difficult to move to or apply in an outside context, as it is revealed through its application. Indeed, as Kogut and Zander (1992) noted, if tacit knowledge can only be learned through its application and acquired through practice, its transfer is risky and costly. As Hakanson (2010) argued, the reason that a firm exists is because it is capable of managing knowledge, in particular, tacit knowledge, more cheaply and efficiently than is possible under other forms of governance.

The second, and the most important, reason why policy should place the firm at the centre of the policy debate is that firms will not fully benefit from external knowledge unless they have sufficient absorptive capacity.[17] Because indigenous R&D and technology transfer share a complementary relationship (e.g. Cohen and Levinthal 1989, Griffith et al. 2004; Hu et al. 2005) instead of a substitutable relationship, firms who undertake in-house R&D are more likely to benefit from technology transfers. For example, Griffith et al. (2004) found that indigenous R&D enhances technology transfer in a panel of industries across twelve OECD countries. Indeed, Hu et al. (2005) found that indigenous R&D significantly complements both domestic and foreign technology transfer based on a large dataset for China's medium-large sized firms. Braga and Willmore (1991) found robust complementarity between R&D and technology imports in Brazilian industry. This complementary relationship also has been found in Taiwan (Kim and Nelson 2000), Korea (Kim 1997) and India (Katrak 1997). This complementary relationship suggests that outsourcing research activities alone is not enough and much more is needed, because external cooperation can possibly stimulate in-house R&D, but it is not able to replace the firms' self-innovation activity. That in-house R&D and technology transfer complement rather than substitute each other implies that firms with high levels of absorptive capacity may have better external networks in terms of breadth and depth, but better networks do not necessarily guarantee firms benefiting from technology transfer if the absorptive capacity is lacking. As Veugelers (1997) concluded: "cooperation in R&D has no significant effect on own R&D unless the firms have an own R&D infrastructure, in which case cooperation stimulates internal R&D expenditures. These results support the idea that indeed absorptive capacity is necessary to be able to capitalise on the complementarities between internal and external know-how" (p. 312).

[17] This seems not to be recognised in the consultation undertaken by BEIS (2018) calling for evidence on what influences the business productivity distribution in the UK, since it is implied that technology and innovation adoption are the major source of differences between frontier firms and those lower down the distribution. Absorptive capacity (and its importance) is not mentioned per se implicitly or explicitly, while we would content that it should be at the core of the debate on the role of policy.

Based on above two reasons, public policy should aim both "… to develop in firms the capabilities needed to search for, recognize, evaluate, assimilate and exploit geographically distant knowledge" (de Jong and Freel, 2010, p. 52), *and* encourage network connections and facilitate collaborations between firms. Policies that improve firm 'receiver competence' (cf. "the ability to organize, co-ordinate and mobilize already available resources and knowledge in such a way as to adapt and integrate new industries in a society" Haraldsen 1998, p.199) are not necessarily inconsistent with the above arguments presented by Metcalfe and Georgiou (1997), because policies designed to strengthen capabilities at the firm level is in line with the role of how market forces determine 'winners'. That is, policies strengthening 'receiver competence' does not imply that they provide firms with an unfair advantage; rather they will ultimately reinforce the economy by achieving an overall improvement in the competitive process.

6. Summary and conclusions

We started by noting that while absorptive capacity is an important concept, it is underutilised by economists e.g., when discussing such issues as what determines productivity growth. After a discussion of how absorptive capacity is defined, where there is essentially common ground across researchers, the paper compares and contrasts how it is typically measured in the business and economics literatures when using micro-data. The business literature more generally uses surveys based on small cross-sections of firms, where the focus is on accurately identifying the processes firms adopt in internalising external knowledge, linking them to separate components of absorptive capacity, and then adequately measuring them; it assumes that researchers have enough information to develop adequate statements capturing the processes, and that firms have the ability to consistently rank these statements in an objective and accurate manner. In contrast, economists generally prefer to use larger, more nationally representative data (often collected by government agencies) that is more objective in that surveyed firms are asked to state if certain activities are taking place, and it is more generalizable since it is obtained from large datasets covering many countries and often for significant time periods. It is not our intention here to state that one approach is superior; in our view, the 'business' literature is more focused on understanding the processes by which absorptive capacity is generated, while economists are more focused on using measures of absorptive capacity to explain what determines business performance.

The rest of the paper shows an extended version of the approach usually taken in the economics literature; extending Harris and Li (2009), we use readily available data from the European Community Innovation Survey to undertake a longitudinal study to consider which firms are most likely to have higher absorptive capacity, whether they maintain this advantage over time, and how important it is in impacting on the propensity of firms to innovate, undertake R&D and export. Since absorptive capacity is about the ability of firms to improve their productivity as they assimilate knowledge from the external environment in which they operate, the final sub-section discussed how such capacity is linked to the development of industrial strategies by policy makers, noting that If firms are not able to learn, and hence gather and make effective use of information from outside the firm, then such policy initiatives are likely to have only a limited impact.

The results, obtained from estimates of absorptive capacity from a structural equation modelling (SEM) approach, were used to show that establishments belonging to multinational firms, those employing relatively more graduates, firms engaged in productivity enhancing activities, and certain high-tech sectors, and/or those located in the Greater South East of England, generally have higher absorptive capacity. Moreover, firms with high (low) absorptive capacity maintained their relative position over time, suggesting a considerable degree of stability over time and thus that it takes a considerable period to build absorptive capacity (or to see it erode).

As to the productivity-enhancing role of absorptive capacity, and relative to other influences, the study showed that absorptive capacity as measured here – net of the impact of foreign-ownership and human capital (proxied by the percentage of graduates employed) – has a substantial influence on exporting, innovation and undertaking R&D, and thus consequently firm-level productivity.

In terms of public policy, we argued that this should aim both to develop in firms the capabilities needed to search for, recognize, evaluate, assimilate and exploit knowledge, *and* encourage network connections and facilitate collaborations between firms. However, the specific approach government should adopt to increasing firm-level absorptive capacity, alongside ensuring that the 'technological infrastructure' surrounding firms allows for knowledge spillovers, is a practical issue requiring further substantive research to understand more fully the specific processes by which firms create (internal and external) knowledge.

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Appendix

Table A.1: (Weighted) Factor loadings from PFA model, GB, 2004-2014

Variable	External knowledge	National cooperation	International cooperation	Specialised knowledge	Business innovation	KMO
Sources of knowledge/info for innovation						
Suppliers	0.6885					0.9322
Clients/customers	0.7176					0.9008
Competitors	0.7194					0.9218
Conferences/trade fairs/exhibitions	0.6798					0.9514
Scientific journals and trade/technical publications	0.6774					0.9348
Professional/industry associations	0.7421					0.9232
Technical/industry standards	0.7236					0.9333
Consultants/labs/R&D institutes				0.5834		0.9182
Universities and other HEIs				0.6923		0.8111
Government/research organisations				0.6367		0.8511
Co-operation partners on innovation activities (national/international)						
Suppliers (national)		0.6779				0.9076
Clients/customers (national)		0.6769				0.9038
Competitors (national)		0.7323				0.9158
Consultants/labs/R&D institutes (national)		0.7115				0.9026
Universities and other HEIs (national)		0.6679				0.8338
Government/research organisations (national)		0.7272				0.8500
Suppliers (international)			0.5639			0.9127
Clients/customers (international)			0.5988			0.9038
Competitors (international)			0.7343			0.9017
Consultants/labs/R&D institutes (international)			0.8011			0.8976
Universities and other HEIs (international)			0.8436			0.8041
Government/research organisations (international)			0.8471			0.8038
Areas of changes of business structure and HRM practices						
New business practices					0.7618	0.9064
New work practices					0.7275	0.9226
New external relations					0.7504	0.9124
New marketing strategies					0.6708	0.9303
Overall						0.8969

Only loadings>0.5 are shown. Note all 5 retained factors have eigenvalues>1. N=79,722

Source: CIS4 – CIS9 surveys

Table A.2: (Weighted) means and standard deviations for variables used in modelling

Variable	definition	Manufacturing		Services		Source
		Mean	Std. Dev	Mean	Std. Dev	
export	Whether establishment sold goods & services outside UK (coded 1)	0.538	0. .498	0.251	0.434	CIS
innovation	Whether establishment produced product or process innovation (coded 1)	0. 401	0.490	0.227	0.418	CIS
R&D	Whether establishment undertook R&D (coded 1)	0.399	0.490	0.217	0.412	CIS
External knowledge	External knowledge latent variable (based on SEM)	0.070	0.313	-0.026	0.273	CIS
National cooperation	National cooperation latent variable (based on SEM)	0.042	0.228	-0.009	0.191	CIS
International cooperation	International cooperation latent variable (based on SEM)	0.009	0.098	0.001	0.090	CIS
Specialised knowledge	Specialised knowledge latent variable (based on SEM)	0.032	0.250	-0.011	0.202	CIS
Business innovation	Establishment engaged in business innovation latent variable (based on SEM)	0.036	0.214	-0.015	0.191	CIS
15-26 employees	Whether establishment employed 15-26 workers (coded 1)	0.301	0.459	0.311	0.463	CIS
27-82 employees	Whether establishment employed 27-82 workers (coded 1)	0.339	0.473	0.284	0.451	CIS
83-256 employees	Whether establishment employed 83-256 workers (coded 1)	0.122	0.328	0.079	0.270	CIS
257+ employees	Whether establishment employed 257+ workers (coded 1)	0.055	0.228	0.041	0.198	CIS
No graduates employed	Whether establishment employed no graduates (coded 1)	0.463	0.499	0.529	0.499	CIS
6-20% graduates employed	Whether establishment employed 6-20% graduates (coded 1)	0.229	0.420	0.151	0.358	CIS
21-50% graduates employed	Whether establishment employed 21-50% graduates (coded 1)	0.069	0.254	0.100	0.300	CIS
51+% graduates employed	Whether establishment employed 51+% graduates (coded 1)	0.038	0.191	0.093	0.291	CIS
ln (age)	(log) of age of establishment in years	2.653	0.664	2.347	0.634	ARD
Multi-region enterprise	Whether establishment belonged to an enterprise with establishments in more than one region (coded 1)	0.172	0.377	0.136	0.343	ARD
Multi SIC enterprise	Whether establishment belonged to an enterprise with establishments in more than one industry (coded 1)	0.268	0.443	0.188	0.391	ARD
Single-plant enterprise	Whether establishment was a single-plant enterprise (coded 1)	0.668	0.471	0.670	0.470	ARD
ln (capital-labour ratio)	(log) capital-to-labour ratio	9.642	1.760	9.201	2.136	ARD
Greater South-east	Whether establishment located in Eastern England, South East, London or South West	0.287	0.452	0.398	0.489	ARD
UK-owned outward FDI	Whether establishment belonged to a UK enterprise with establishments overseas (coded 1)	0.050	0.218	0.025	0.156	AFDI
US-owned	Whether establishment was owned by a US enterprise (coded 1)	0.031	0.173	0.013	0.113	ARD
EU-owned	Whether establishment was owned by a EU enterprise (coded 1)	0.054	0.225	0.026	0.159	ARD
Other foreign-owned	Whether establishment was owned by a other foreign-owned enterprise (coded 1)	0.021	0.145	0.010	0.101	ARD
Links with HEI	Whether establishment sourced information or cooperated with HEI (coded 1)	0.257	0.437	0.140	0.347	CIS
ln (Herfindahl index)	(log) Herfindahl index of industry concentration (5-digit level)	-2.705	0.824	-3.009	0.855	ARD

ln (industry agglomeration)	(log) percentage of R&D stock in each industry (using 3-digit 1992 SIC) in travel-to-work area in which establishment located	-1.813	3.478	-2.150	4.130	BERD
ln (diversification)	(log) proportion of 215 3-digit SIC92 industries with R&D stock>0 in travel-to-work area in which establishment located	-1.317	0.665	-1.247	0.769	BERD
ln (Enterprise employment)	(log) employment of (multi-SIC) enterprise to which establishment belongs	3.877	1.506	3.551	1.266	ARD
(unweighted) N	(unweighted) N	6,874		15,266		

Table A.3: Marginal effects of absorptive capacity (the median value to the 99 percentile) on exporting, innovation and R&D in GB, 2004-2014 (by sector): various models

	Manufacturing			Services		
	Exporting	Innovation	R&D	Exporting	Innovation	R&D
Baseline model (Table 7)						
External knowledge	0.136***	0.472***	0.400***	0.099***	0.543***	0.436***
National cooperation	–	0.349***	0.128***	–	0.223***	0.091***
International cooperation	–	–	–	0.039***	–	–
Specialised knowledge	-0.072***	-0.216***	-0.123***	-0.056***	-0.140***	-0.071***
Business innovation	0.042***	0.268***	0.384***	0.055***	0.376***	0.424***
Matching model (Table S.4)						
External know.	0.076***	0.339***	0.290***	0.072***	0.441***	0.349***
National coop.	–	0.349***	0.123***	–	0.267***	0.134***
International coop.	–	–	–	0.043***	–	–
Global know.	-0.039***	-0.244***	-0.111***	-0.048***	-0.136***	-0.069***
Business innovation	0.028***	0.238***	0.317***	0.053***	0.383***	0.415***
Observations	4,583	4,583	4,583	10,463	10,463	10,463
No. of enterprises	3,173	3,173	3,173	7,458	7,458	7,458
Wooldridge model (Table S.4)						
External know.	0.136***	0.470***	0.404***	0.010***	0.545***	0.446***
National coop.	–	0.363***	0.132***	–	0.224***	0.087***
International coop.	–	–	–	0.039***	–	–
Global know.	-0.081***	-0.218***	-0.125***	-0.049***	-0.140***	-0.069***
Business innovation	0.050***	0.280***	0.417***	0.056***	0.376***	0.435***

*** p<0.01, ** p<0.05, * p<0.1

Unpublished appendix

Table S.1 Articles listed in ECONLIT[a] in journals attributed to economics (using ABS[b] list) that included a variable(s) measuring absorptive capacity, 2015-2018

Year	Author(s)	Journal	Title	Type of article	AC measurement
2015	Arvanitis and Woerter	Economics of Innovation and New Technology	Exploration or Exploitation of Knowledge from Universities: Does It Make a Difference?	Empirical	R&D
2015	Buchmann and Pyka	Economics of Innovation and New Technology	The Evolution of Innovation Networks: The Case of a Publicly Funded German Automotive Network	Empirical	Patents
2015	D'Souza and Kulkami	International Journal of Production Economics	A framework and model for absorptive capacity in a dynamic multi-firm environment	Empirical	R&D
2015	Eren et al	Eastern European Economics	Mergers and Acquisitions Versus Greenfield Investment, Absorptive Capacity, and Economic Growth: Evidence from 12 New Member States of the European Union	Empirical	FDI
2015	Hubler	The Journal of International Trade and Economic Development	A model of endogenous growth that elucidates the complexity of South–North convergence	Empirical	Human capital
2015	Iamsiraroj and Ulubasoglu	Economic Modelling	Foreign Direct Investment and Economic Growth: A Real Relationship or Wishful Thinking?	Empirical	Financial development and trade openness
2015	Iwasaki and Suganuma	Economic Change and Restructuring	Foreign direct investment and regional economic development in Russia: an econometric assessment	Empirical	R&D
2015	Kim	Empirical Economics	Productivity Spillovers from FDI and the Role of Domestic Firm's Absorptive Capacity in South Korean Manufacturing Industries	Empirical	R&D
2015	Pinto et al	Regional Studies	Universities and Knowledge-Intensive Business Services (KIBS) as Sources of Knowledge for Innovative Firms in Peripheral Regions	Empirical	R&D
2015	Toole et al	Economics of Innovation and New Technology	University Research Alliances, Absorptive Capacity, and the Contribution of Startups to Employment Growth	Empirical	Human capital
2015	Zhang	Contemporary Economic Policy	What Drives Export Competitiveness? The Role of FDI in Chinese Manufacturing	Empirical	R&D
2016	Berchicci et al	Industrial and Corporate Change	Remote collaboration and innovative performance: the moderating role of R&D intensity	Empirical	R&D
2016	Caragliu and Nijkamp	Journal of Economic Geography	Space and knowledge spillovers in European regions: the impact of different forms of proximity on spatial knowledge diffusion	Empirical	R&D
2016	Combes et al	Applied Economics	Structural Shifts in Aid Dependency and Fiscal Policy in Developing Countries	Empirical	Human capital
2016	Galbreadth	Regional Studies	Exploratory Study of Climate Change Innovations in Wine Regions in Australia	Empirical	Human capital
2016	Glas et al	Applied economic letters	Catching up of emerging economies: the role of capital goods imports, FDI inflows, domestic investment and absorptive capacity	Empirical	Human capital
2016	Gonel and Aksoy	The Journal of International Trade and Economic Development	Revisiting FDI-Led Growth Hypothesis: The Role of Sector Characteristics	Empirical	Human capital
2016	Hassine et al	Applied Economics	The Two Ways of FDI R&D Spillovers: Evidence from the French Manufacturing Industry	Empirical	R&D
2016	Hubler et al	The World Economy	Indicators of Absorptive Capacity and Import-induced South–North Convergence in Labour Intensities	Empirical	Human capital
2016	Manuel et al	Regional Studies	Access to Universities' Public Knowledge: Who is More Regionalist?	Empirical	R&D

2016	Pavlinek and Zizalova	Journal of Economic Geography	Linkages and Spillovers in Global Production Networks: Firm-Level Analysis of the Czech Automotive Industry	Empirical	Human capital
2016	Presbitero	Journal of deveopment economics	Too much and too fast? Public investment scaling-up and absorptive capacity	Empirical	R&D
2016	Wang and Wong	Atlantic Economic Journal	Effects of Foreign Direct Investment on Firm-level Technical Efficiency: Stochastic Frontier Model Evidence from Chinese Manufacturing Firms	Empirical	R&D
2017	Behera	Economics of Innovation and New Technology	Regional Foreign Direct Investment and Technology Spillover: Evidence across Different Clusters in India	Empirical	R&D
2017	Ergun et al	Asian Economic Papers	Vertical and Horizontal Spillovers from Foreign Direct Investment: Evidence from Malaysian Manufacturing	Empirical	TFP
2017	Filippetti et al	Cambridge Journal of Economics	The Impact of Internationalization on Innovation at Countries' Level: The Role of Absorptive Capacity	Empirical	R&D
2017	Giannoccaro	International Journal of Production Economics	An Ising-based dynamic model to study the effect of social interactions on firm absorptive capacity	Simulation, theoretical model	Human capital
2017	Huang and Zhang	China Economic Review	How does outward foreign direct investment enhance firm productivity? A heterogeneous empirical analysis from Chinese manufacturing	Empirical	R&D
2017	Jacobs et al	Eastern European Economics	Mutual Productivity Spillovers in Slovakia: Absorptive Capacity, the Technology Gap, and Nonlinear Effects	Empirical	Intangible assets relevant
2017	Neil Foster-McGregor, Johannes Pöschl & Robert Stehrer	Economics of Innovation and New Technology	The importance of absorptive capacities: productivity effects of international R&D spillovers through intermediate inputs	Empirical	R&D
2017	Okafor et al	The World Economy	Imported Intermediates, Absorptive Capacity and Productivity: Evidence from Ghanaian Manufacturing Firms	Empirical	TFP
2017	Smit	Annals of Regional Science	Innovation through New Blood	Empirical	Human capital
2017	Smith and Thomas	Regional Studies	Regional conditions and innovation in Russia: the impact of foreign direct investment and absorptive capacity	Empirical	FDI
2017	Yang et al	International Journal of Production Economics	Leveraging selected operational improvement practices to achieve both efficiency and creativity: A multi-level study in frontline service operations	Empirical	Human capital
2018	Enrique López-Bazo & Elisabet Motellón	Regional Studies	Innovation, heterogeneous firms and the region: evidence from Spain	Empirical	R&D

[a] Search of https://www.aeaweb.org/econlit/ (July 2018) by using 'absorptive capacity' as a keyword or in the abstract. Note, 178 articles in total met this criteria, and 71 of them were from Economic journals (as featured in ABS list of journals). Of the 71 articles, 7 have little to do with AC, 16 have no available full-text, and 13 have not specified the measurement of AC. This leaves 35 articles as listed in the table.

[b] See https://charteredabs.org/academic-journal-guide-2018/.

Table S.2: Equation-level goodness of fit of SEM model

	Variance				
	fitted	predicted	residual	mc	mc^2
Observed					
Suppliers	0.205	0.094	0.110	0.679	0.461
Clients/customers	0.218	0.129	0.089	0.770	0.593
Competitors	0.185	0.090	0.095	0.697	0.486
Conferences/trade fairs/exhibitions	0.121	0.050	0.072	0.639	0.409
Scientific journals and trade/technical publications	0.093	0.035	0.059	0.610	0.372
Professional/industry associations	0.130	0.059	0.071	0.676	0.457
Technical/industry standards	0.138	0.066	0.072	0.691	0.477
Consultants/labs/R&D institutes	0.083	0.063	0.072	0.511	0.261
Universities and other HEIs	0.043	0.020	0.022	0.690	0.475
Government/research organisations	0.044	0.023	0.021	0.720	0.519
Suppliers (national)	0.097	0.050	0.047	0.716	0.513
Clients/customers (national)	0.107	0.061	0.046	0.757	0.573
Competitors (national)	0.052	0.023	0.029	0.665	0.442
Consultants/labs/R&D institutes (national)	0.048	0.020	0.028	0.642	0.412
Universities and other HEIs (national)	0.038	0.012	0.026	0.566	0.320
Government/research organisations (national)	0.031	0.010	0.021	0.576	0.332
Suppliers (international)	0.034	0.008	0.027	0.474	0.225
Clients/customers (international)	0.036	0.010	0.027	0.514	0.264
Competitors (international)	0.016	0.006	0.010	0.628	0.395
Consultants/labs/R&D institutes (international)	0.014	0.008	0.006	0.741	0.550
Universities and other HEIs (international)	0.011	0.007	0.003	0.819	0.670
Government/research organisations (international)	0.009	0.006	0.003	0.808	0.653
New business practices	0.158	0.054	0.104	0.584	0.341
New work practices	0.139	0.048	0.092	0.586	0.343
New external relations	0.115	0.046	0.070	0.629	0.396
New marketing strategies	0.149	0.061	0.088	0.640	0.410
export	0.191	0.013	0.178	0.262	0.069
R&D	0.189	0.078	0.111	0.641	0.411
Innovation	0.208	0.068	0.140	0.571	0.326
Latent					
External knowledge	0.094	0.065	0.030	0.829	0.687
National cooperation	0.050	0.021	0.029	0.653	0.427
International cooperation	0.008	0.001	0.007	0.269	0.072
Specialised knowledge	0.063	0.017	0.047	0.511	0.261
Business innovation	0.054	0.033	0.021	0.784	0.615
overall					

mc = correlation between the dependent variable and its prediction
mc^2 = the Bentler-Raykov squared multiple correlation coefficient

Table S.3: Correlations between AC indices from SEM and Factor Analysis (FA) models

	External knowledge ((FA)	National cooperation ((FA)	International cooperation ((FA)	Specialised knowledge ((FA)	Business innovation ((FA)	External knowledge (SEM)	National cooperation (SEM)	International cooperation (SEM)	Specialised knowledge (SEM)	Business innovation (SEM)
External knowledge ((FA)	1.000									
National cooperation ((FA)	0.349	1.000								
International cooperation ((FA)	0.419	0.319	1.000							
Specialised knowledge ((FA)	0.202	0.354	0.192	1.000						
Business innovation ((FA)	0.230	0.201	0.079	0.166	1.000					
External knowledge (SEM)	*0.966*	0.474	0.549	0.292	0.347	1.000				
National cooperation (SEM)	0.513	*0.960*	0.457	0.394	0.174	0.623	1.000			
International cooperation (SEM)	0.184	0.311	*0.178*	0.983	0.207	0.279	0.363	1.000		
Specialised knowledge (SEM)	0.659	0.391	0.351	*0.269*	0.772	0.734	0.467	0.277	1.000	
Business innovation (SEM)	0.594	0.451	0.960	0.262	*0.154*	0.720	0.607	0.246	0.475	1.000
AC index (SEM)	0.818	0.608	0.736	0.388	0.270	0.920	0.758	0.369	0.654	0.885

N= 78,938

Table S.4: (Weighted) Estimates of (stepwise) random-effects probit models determining exporting, R&D and innovation, GB, 2004-2014 (by sector) – marginal effects reported: 'matching' and Wooldridge models

	Manufacturing						services					
	Exporting		Innovation		R&D		Exporting		Innovation		R&D	
	matched	Wooldridge	matched	Wooldridge	matched	Wooldridge	matched	Wooldridge	matched	Wooldridge	matched	Wooldridge
$R\&D_{t-1}$	–	–	–	–	0.209***	0.034***			0.035***	0.025***	0.154***	0.050***
$innovation_{t-1}$	–	–	0.192***	0.066***	0.036***	0.018***			0.145***	0.055***	0.023***	0.014***
$export_{t-1}$	0.363***	0.093***	–	–	0.068***	0.053***	0.375***	0.108***	0.030***	0.026***	0.042***	0.028***
$export_0$		0.273***	–	–	–	–	–	0.200***	–	–	–	–
$Innovation_0$	–	–	–	0.095***	–	–	–	–	–	0.043***	–	–
$R\&D_0$	–	–	–	–	–	0.128***	–	–	–	–	–	0.052***
External knowledge[a]	0.027***	0.045***	0.119***	0.136***	0.100***	0.106***	0.020***	0.026***	0.104***	0.096***	0.084***	0.078***
National cooperation[a]	–	–	0.066***	0.066***	0.027***	0.026***	–	–	0.049***	0.035***	0.026***	0.016***
International cooperation[a]	–	–	–	–	–	–	0.006***	0.005***	–	–	–	–
Specialised knowledge[a]	-0.008***	-0.016***	-0.052***	-0.058***	-0.023***	-0.029***	-0.010***	-0.010***	-0.045***	-0.040***	-0.015***	-0.016***
Business innovation[a]	0.009***	0.016***	0.074***	0.071***	0.102***	0.100***	0.015***	0.016***	0.085***	0.071***	0.099***	0.077***
15-26 employees	0.035***	0.034***	0.041***	0.031***	–	–	0.034***	0.025***	–	–	–	–
27-82 employees	0.058***	0.045***	0.045***	0.044***	–	–	0.037***	0.035***	–	–	–	–
83-256 employees	0.068***	0.047***	0.069***	0.062***	–	–	0.042***	0.035***	–	–	–	–
257+ employees	–	–	0.053***	0.051***	0.026***	0.017**	0.060***	0.054***	–	–	0.022***	0.011***
No graduates employed	-0.080***	-0.106***	–	–	-0.047***	-0.076***	-0.072***	-0.073***	–	–	-0.027***	-0.045***
6-20% graduates employed	–	–	0.028***	0.025***	–	–	–	–	–	–		
21-50% graduates employed	0.067***	0.081***	0.040***	0.038***	0.033***	0.039***	0.025***	0.026***	–	–	–	–
51+% graduates employed	–	–	–	–	–	–	0.069***	0.054***	–	–	0.035***	0.024***
ln (age)	0.027***	0.019***	–	–	–	–	0.018***	0.009***	0.019***	0.006***	–	–
Multi-region enterprise	–	–	–	–	–	–	0.018***	0.018***	0.030***	0.019***	–	–
Single-plant enterprise	–	–	–	–	–	–	–	–	0.034***	0.014***	–	–
ln (capital-labour ratio)	–	–	–	–	–	–	0.006***	0.004***	–	–	0.007***	0.004***
Greater South-east	–	–	–	–	–	–	0.019***	0.016***	–	–	–	–
UK-owned outward FDI	0.053***	0.039***	–	–	–	–	0.070***	0.051***	–	–	–	–
US-owned	0.089***	0.109***	–	–	–	–	0.069***	0.039***	–	–	–	–
EU-owned	0.060***	0.056***	–	–	–	–	0.089***	0.070***	–	–	-0.049***	-0.031***
Other foreign-owned	0.118***	0.070***	–	–	–	–	0.110***	0.093***	–	–	–	–
Aberdeen	–	–	–	–	–	–	0.185***	0.083***	-0.067***	-0.048***	–	–
Bristol	–	–	-0.055*	-0.119***	0.247***	0.101***	-0.042***	-0.053***	–	–	–	–
Edinburgh	–	–	–	–	–	–	0.095***	0.053***	–	–	–	–

Links with HEI	0.044***	0.034***	0.042***	0.039***	0.018***	0.025***	–	–	0.055***	0.041***	0.020***	0.013***
ln (Herfindahl index)	–	–	–	–	–	–	0.011***	0.011***	–	–	-0.011***	-0.007***
ln (industry agglomeration)	0.004***	0.004***	–	–	–	–	0.005***	0.004***	–	–	–	–
ln (diversification)	–	–	-0.012***	-0.006***	-0.007***	-0.006***	-0.019***	-0.012***	-0.010***	-0.006***	–	–
ln (Enterprise employment)	–	–	–	–	–	–	-0.017***	-0.015***	–	–	–	–
Leicester	–	–	0.025	-0.059***	–	–	–	–	-0.239***	-0.113***	–	–
Liverpool	–	–	–	–	–	–	-0.120***	-0.115***	-0.121***	-0.087***	–	–
Manchester	–	–	0.264***	0.119***	–	–	–	–	–	–	–	–
Sheffield	–	–	–	–	-0.132***	-0.113***	0.071***	0.048***	–	–	–	–
East Midlands	–	–	–	–	–	–	0.020***	0.022***	–	–	-0.026***	-0.018***
North East	-0.079***	-0.042***	–	–	–	–	–	–	-0.062***	-0.031***	–	–
Scotland	–	–	–	–	–	–	–	–	–	–	-0.039***	-0.026***
Wales	–	–	–	–	–	–	–	–	-0.031***	-0.028***	–	–
2008	0.104***	0.072***	-0.060***	-0.035***	-0.072***	-0.082***	0.080***	0.064***	-0.108***	-0.065***	-0.107***	-0.055***
2010	0.119***	0.111***	0.061***	0.046***	-0.099***	-0.104***	0.075***	0.056***	–	–	-0.168***	-0.104***
2012	–	–	–	–	-0.137***	-0.145***	–	–	-0.053***	-0.036***	-0.186***	-0.113***
2014	0.080***	0.062***	–	–	-0.113***	-0.136***	0.047***	0.043***	-0.056***	-0.027***	-0.173***	-0.107***
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,583	6,874	4,583	6,874	4,583	6,874	10,463	15,266	10,463	15,266	10,463	15,266
No. of enterprises	3,173	4,451	3,173	4,451	3,173	4,451	7,458	9,909	7,458	9,909	7,458	9,909
Rubin's B[b]	23.4		23.4		23.4		24.4		24.4		24.4	
Rubin's R[b]	1.17		1.17		1.17		1.18		1.18		1.18	
Pseudo-R^2	0.470	0.473	0.277	0.358	0.333	0.450	0.411	0.422	0.310	0.376	0.329	0.434

[a] These variables in Table A.2 have been standardised (mean subtracted and divided by standard deviation).

[b] Measure of appropriateness of the overlap between the 'treatment' and 'control' groups (acceptable if B<25% and 0.5<R<2). See Rubin (2001). Other tests based on 'ptest' in STATA are available on request, which confirm that 'matching' has been done on well-defined sub-groups.

Figure S.1: Journal articles with ‘absorptive capacity’ as keyword or in abstract, 1999-2018 (based on Scopus search, July 2018)